# The Unusual Solar Particle Events of August 2002

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## Abstract

Several highly unusual solar particle events occurred in August 2002, with high $^3$He/$^4$He ratios and enormous enhancements of heavy isotopes [5]. By examining proton, electron, and heavy ion intensities, H$\alpha$, X-ray, and radio flares and particle arrival times relative to them and to coronal mass ejections, we find that the 20 August 2002 event was the largest impulsive event yet seen in this solar cycle at energies >10 MeV/nucleon.

## 1. Introduction

Solar energetic particle (SEP) events are classified as gradual or impulsive [3]. Gradual events tend to be low in $^3$He/$^4$He and near-coronal (on average) in their composition. They last for days and are associated with gradual X-ray flares, type II radio bursts, and large, wide, fast coronal mass ejections (CMEs). Impulsive events are enriched in electrons, $^3$He, and heavy ions. The SEP events and associated X-ray flares are of short duration. If any CMEs are present they tend to be small and narrow [1]. It is thought that particles observed in gradual events are mainly shock-accelerated coronal or suprathermal material, while those in impulsive events are flare-accelerated material. Here we decide whether the peculiar August 2002 SEP events [5] were gradual or impulsive by examining both in-situ particle data and remote sensing flare observations.

## 2. In-Situ Particle Observations

We consider 4 SEP events from 3-20 August 2002 as highlighted in Fig. 1, for which $^3$He/$^4$He>0.12 at 5 MeV/nucleon and Fe/O>1 at 12-60 MeV/nucleon [5] as measured by the Solar Isotope Spectrometer (SIS) on the Advanced Composition Explorer (ACE). The 14 April 2001 event, which has been called the largest impulsive event of this solar cycle [4], is shown for comparison; it was followed on 15 April by a large, gradual event. Note that the peak oxygen intensity in the

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20 August 2002 event was similar to that in the large 15 April 2001 event, but the proton intensity was ∼300 times lower! At the energies shown, the 20 August event electron/proton ratio was the highest observed by ACE to date.

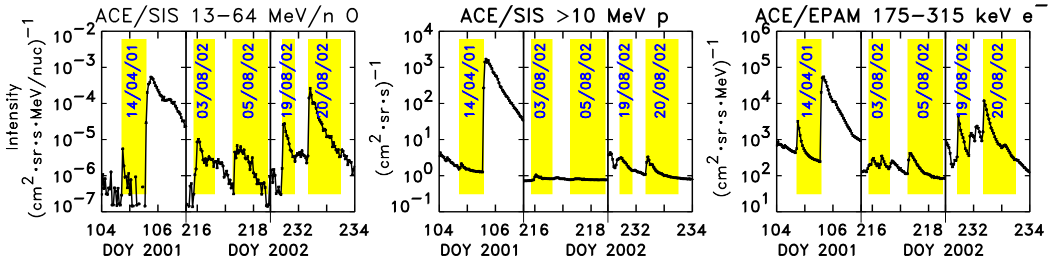


**Fig. 1.** SEP time profiles using oxygen (*left*), protons (*center*), and electrons (*right*).

Relative to large events over the past 5 years with similar oxygen intensities, all four August 2002 events have uniquely low proton abundances (Fig. 2). The 14 April 2001 event looks similar, but peak oxygen intensities in the 20 August event are ∼40 times greater, larger than for any similar event shown.

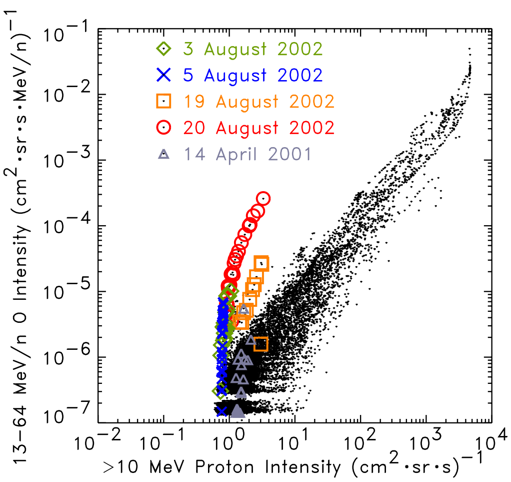


**Fig. 2.** Hourly ACE/SIS oxygen vs. proton rates, Aug 1997-Dec 2002.

Fig. 3 shows the reciprocal of $\beta$=velocity/c plotted vs arrival time for each particle. Velocity dispersion is often present, with faster ions arriving earlier than slower ones. If particles left at the same time as the flares listed in Table 1, they would arrive along the tilted lines after traveling 1.2 AU. The association of flares with SEPs is obvious for the 19-20 August 2002 and April 2001 events (although a ∼1.9 AU pathlength may fit the 15 April 2001 event better), but not as clear for the 3-5 August 2002 events. While a few particles seem to arrive soon after the 3 August X1.0 flare, most first appear ∼5 hours later. Magnetic connectivity may have first become favorable at this time, or particle scattering may have delayed the particle arrival. The anisotropy observed by SIS was small for the 3-5 August events but very large and long lasting for the 19-20 August events, indicating very little local scattering during these later events.

The calculated injection time into interplanetary space for each detected heavy ion (assuming scatter-free propagation and a 1.2 AU pathlength) appears as a 1-minute binned histogram (uncorrected for instrument livetime) in Fig. 4. For comparison, the GOES 1-8 Å soft X-ray flux (time-shifted for its 1 AU pathlength) is also shown. Note that the X-ray flares of 19 and 20 August were much more

**Table 1.** Hα and X-Ray Flare Data from NOAA (http://www.sel.noaa.gov)

| dd/mm/yy | Begin | Max | End | I/B | X-Ray | Region | Location | Radio |
|---|---|---|---|---|---|---|---|---|
| **14/04/01** | **17:25** | **17:38** | **18:41** | **SF** | **M1.0** | **9415** | **S16W71** | **III/1** |
| **15/04/01** | **13:36** | **13:49** | **15:35** | **2B** | **X14.4** | **9415** | **S20W85** | **III/1; II/3; IV/3** |
| 03/08/02 | 19:10 | 19:10 | 19:16 | SF | X1.0 | 0039 | S16W76 | III/2 |
| 03/08/02 | 21:25 | 21:32 | 21:37 | | C6.1 | 0044 | S24W88 | |
| 04/08/02 | 08:58 | 09:55 | 10:33 | | M6.6 | | | III/1 |
| 04/08/02 | 14:52 | 14:58 | 15:02 | | C4.8 | | | III/1 |
| 05/08/02 | 05:15 | 05:17 | 05:28 | SF | C4.8 | 0057 | S10W43 | III/1 |
| **19/08/02** | **10:31** | **10:41** | **11:03** | **SF** | **M2.0** | **0069** | **S12W25** | **III/3** |
| 19/08/02 | 14:25 | 14:33 | 15:09 | SF | C9.5 | 0069 | S13W30 | CTM/1 |
| 19/08/02 | <20:52 | ∼21:01 | >21:22 | 1B | M3.1 | 0069 | S11W33 | III/3 |
| 20/08/02 | 01:35 | 01:44 | 02:17 | 1N | M5.0 | 0069 | S11W35 | III/3 |
| 20/08/02 | 02:55 | 02:56 | 03:14 | 1N | M1.4 | 0069 | S10W36 | |
| **20/08/02** | **08:25** | **08:26** | **08:37** | **1B** | **M3.4** | **0069** | **S10W38** | **V/3; III/2** |

Times are for Hα flare unless no reports exist, in which case X-ray event timing was used.
Events in **bold** are clearly associated with particle events discussed here.

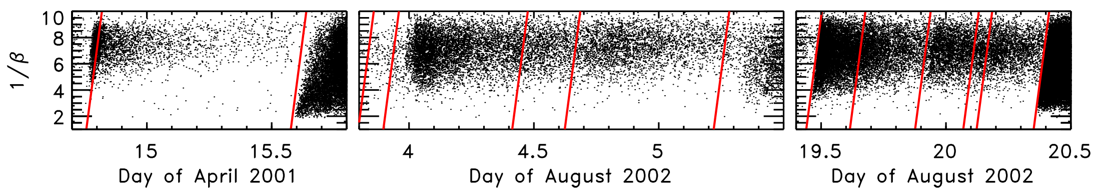


**Fig. 3.** SIS heavy ion velocity dispersion compared with X-ray flares (*see text*).

"impulsive" than that of 14 April 2001, which had an extended, complex structure. Particle onset in the 14 April event seems to be delayed relative to the X-rays by ∼10 min, but could instead be related to a second injection ∼10 min after the first flare. The delay is >0.5 hr in the 15 April 2001 event, typical of gradual events [2]. But in the 19-20 August events the delays are only 3-5 min! Even if the particles were shock-accelerated (for which there is no evidence), at a typical shock velocity of ∼1000 km/s they must have originated within ∼0.5 solar radius of the Sun's surface, deep in the corona.

## 3. Remote Sensing Observations

Nearly all flares in Table 1 had metric type III bursts associated with beamed electrons. Lower frequency Wind/WAVES radio data (http://lep694.gsfc.nasa.gov/waves/waves.html) show a complex series of type III bursts lasting for >1 hr at 10 MHz for the 14 April 2001 event, while the 20 August 2002 event was a simple, short burst of ∼6 min. At 10 MHz the 20 August event was the most intense August event in Table 1. None of these August events had metric type II bursts arising from coronal shocks. However, Wind/WAVES did detect a faint, intermittent interplanetary type II burst accompanying the 3 August X1.0 flare, but it is unclear (Figs. 3 & 4) if this flare is related to the observed SEP event.

Although identified as impulsive [4], the 14 April 2001 event clearly has a wide (∼110°), moderately fast (830 km/s), bright CME [4] in SOHO/LASCO

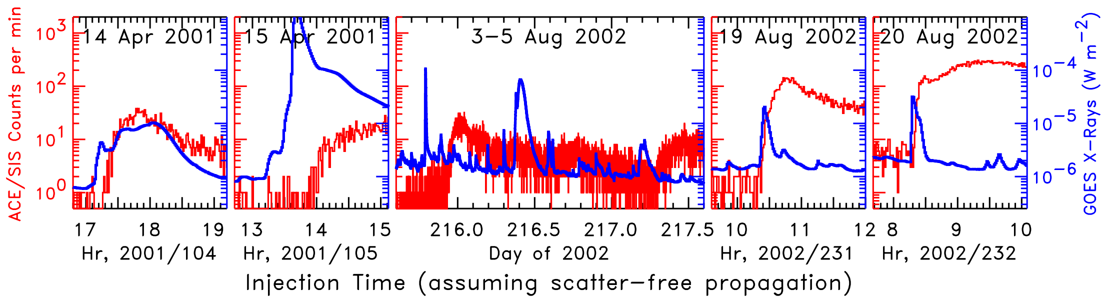


**Fig. 4.** Injection time profiles of SIS heavy ions (*red/light grey, left scale*) and GOES 8 1-8 Å X-rays (*blue/dark grey, right scale*), assuming scatter-free propagation (at best valid only for particle onsets).

coronagraph images (http://lasco-www.nrl.navy.mil/daily_mpg/). Of the four August 2002 events, only 3 August had a comparably large, bright CME associated with the X1.0 flare which, again, might be unrelated to the SEP event. Although not on the LASCO preliminary CME list, inspection of LASCO imagery shows a small, faint CME for the 20 August SEP event. However, even impulsive events can have small CMEs associated with them [1,4].

## 4. Conclusions

It is difficult to identify with certainty X-ray, H$\alpha$, or radio counterparts to the 3-5 August SEP events. Their composition [5] appears impulsive, but a large X-ray flare *near* the time of the 3 August event had a CME and type II burst like a gradual event, so more study is needed. Counterparts to the 19 and 20 August events are easy to identify, and both are consistent with being impulsive events. This makes the 20 August 2002 event the largest impulsive event of solar cycle 23 observed so far in terms of >10 MeV/nucleon particle intensity, far larger (and in all respects more "impulsive") than the previous contender, 14 April 2001.

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## 5. References

1. Kahler, S. W., Reames, D. V., & Sheeley, N. R. Jr. 2001, ApJ 562, 558
2. Mewaldt, R. A., et al. 2003, Proc. 28th ICRC (Tsukuba), this conference
3. Reames, D. V. 1995, Rev. Geophys. 33, 585
4. Tylka, A. J., et al. 2002, ApJL 581, L119
5. Wiedenbeck, M. E., et al. 2003, Proc. 28th ICRC (Tsukuba), this conference